



Fate of the Caribou Project

2022 NSF Annual Report

Reporting Period: 11-01-2021 to 11-01-2022

Prepared by Anna Brose

ACCOMPLISHMENTS

What are the major goals of the project?

Caribou (*Rangifer tarandus*) are the most widespread large mammal of the Arctic and consequently play an integral role in the culture and lifeways of Indigenous and settler peoples of the north. Climate change threatens the ecological, cultural, and economic role of caribou. The goal of the Fate of the Caribou project is to advance understanding of the coupled human-natural system of the Arctic to inform the adaptations of our collaborating communities to climate-induced changes in caribou distributions. Using an unprecedented, shared dataset, we will implement a large-scale, comparative suite of analyses across multiple caribou herds in North America, developing novel ecological modeling and environmental sensing tools at a near-continental scale, motivated and led by the concerns of local communities and Indigenous governing bodies.

Our objectives are to:

1. Build on new and existing partnerships with local communities and Indigenous, state, territorial, and federal governments in Alaska and Canada to share data and tools, and to guide research questions;
2. Develop dynamic field, remote sensing, and community-derived environmental datasets at a near-continental scale to measure the effects of human development and climate change on caribou and their habitat;
3. Identify continental-scale and herd-specific processes that control the dynamics and distributions of caribou populations;
4. Link environmental change, especially human development, directly to demographic processes and population dynamics using caribou movement and behavioral mechanisms;
5. Assemble and synthesize dynamic environmental layers of vegetation change, fire dynamics, snow quality, and human infrastructure;
6. Make significant methodological advances in ecological, behavioral, habitat, and population modeling and in frameworks for the co-production of knowledge with Indigenous partners;
7. Generate new spatial data products and dynamic data visualizations that can be used by resource management organizations and the scientific community;
8. Develop a web application that allows managers, community members, and scientists to dynamically select, view, and interact with our data products at 30 m resolution;
9. Support three postdoctoral researchers, three PhD students, and several undergraduate technicians in the fields of wildlife ecology, environmental informatics, and natural resource management.

What was accomplished under these goals and objectives?

Major Activities: During the first year of the project, we have strengthened the partnerships between the co-PIs and collaborating communities and governments through planning meetings and consultations, thereby refining our initial research questions. This knowledge sharing has steered the development of new spatial tools to measure the social behavior of caribou in relation to their environment, laid the

groundwork for a synthetic model of caribou population dynamics, and identified geographic areas of focus for the expansion of remote sensing tools to track environmental changes in northern Canada. Three postdoctoral researchers and four PhD students have been recruited, and the search is underway for a fourth postdoctoral researcher and an additional PhD student. To date, the project has directly and indirectly supported the publication of six scientific papers, with 2-3 more under review or in press, as well as several popular articles, TV and radio news segments, and a project website and Twitter account to disseminate results.

Specific Objectives: Our partnerships with Indigenous governments and caribou co-management boards have led to the development of an online storymap (an interactive storytelling and data visualization platform) and brochure outlining our recent movement analysis and Indigenous knowledge about the Bathurst Caribou Herd in northern Canada (see attached project proposal). This project is well underway, incorporating partners from the Wek'èezhii Renewable Resources Board, Tłıchǫ Government, Government of the Northwest Territories, and the Wyoming Migration Initiative/Global Initiative on Ungulate Migration. Building on previous collaboration with these partners, our group is providing spatial analysis of Bathurst caribou migration shifts and leading the design and development process for the storymap and brochure. If successful, this effort may be expanded to create similar resources on other caribou herds or to examine specific challenges to caribou populations such as the proliferation of human infrastructure in their habitat.

Our ongoing analysis of caribou movement and population dynamics has produced new insights into the foraging behavior and calving timing at the herd- and continental-scales. Our findings indicate that caribou foraging behavior may be negatively impacted by insect harassment, which is increasing as the climate changes. Further, we have demonstrated that weather patterns are affecting the ability of cow caribou to reach the safety of their calving grounds before giving birth, which could have population-level impacts as calves are less likely to survive if born outside of the calving grounds. This analysis will be further refined as we continue to develop a quantitative method for delineating calving grounds based on caribou GPS collar data and behavior.

The concept of using behavioral indicators from GPS collar data is an emerging field. As GPS collar technology has improved, the resolution of collar data has increased, allowing for finer-scale behavioral analysis. We capitalized on this change by developing analytical tools to detect caribou parturition timing and rates, insect harassment, and other demographic events through behavioral cues in GPS collar data. Several of these indicators are now available to other caribou researchers through our Tuktutools R package. This grant supports the continued development and dissemination of these tools.

Further analysis is underway to build a synthetic population model for caribou using the demographic and environmental indicators we are developing. Team members and a PhD student at the University of Maryland are laying the groundwork of this mathematical model, which will lend insight to caribou population dynamics at a large spatial and temporal scale. We have also recruited a post-doctoral researcher to map vegetation changes and snow and fire impacts in northern Canada using remote sensing, building on previous mapping of northern Alaska conducted by our team members. Three additional PhD students have been recruited to generate new methods of measuring the impacts of human infrastructure and climatic changes using acoustic monitoring, remote sensing, and GPS collars.

PI Gurarie travelled to Denver, CO in December 2021 to participate in data sharing with the National Park Service. This data is restricted in nature and requires in-person data sharing, and is critical to Gurarie's ongoing analysis of the spatial distribution of caribou mortalities in the Western Arctic Caribou Herd.

Several project team members met in Syracuse, NY in April 2022 to conduct project and communication planning. Three team members traveled to and participated in the Joint Meeting of the Ecological Society of America and Canadian Society for Ecology and Evolution in Montréal, Québec, Canada in August 2022. These travel activities contributed significantly to the establishment of this project as a collaborative.

Postdoctoral Researcher Ehlers traveled to Alaska (July 25 – August 19, 2022) to conduct fieldwork and meet with collaborators from natural resource agencies and caribou management boards. While there, Ehlers observed the habitat and animals of the Fortymile Caribou Herd as part of her research on Fortymile caribou foraging ecology using GPS collars fitted with video cameras. She also coordinated with research colleagues to interview hunters and collect biological samples during the annual caribou harvest; samples were used to assess the nutritional condition of harvested animals. Additionally, Ehlers held in-person meetings to collaborate on, develop, and revise a co-authored manuscript.

Significant Results: Analysis conducted by team members at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) has revealed previously unknown patterns in the timing and synchrony of caribou calving at a continental scale. By bringing together collaborators from across northern Alaska and Canada, we compiled a near-complete dataset of caribou GPS collar data from the 11 herds of migratory tundra caribou in North America. Employing our behavioral analysis tools, our team showed that the synchrony of calving is strong within each herd and between neighboring herds, likely driven by local environmental conditions. However, herds that were geographically further from one another showed less synchrony in calving, indicating that local conditions, rather than continental climatic conditions, are driving calving timing.

Further, our team demonstrated that weather conditions in the months prior to calving were critical in determining the timing and location of calving. Most striking was the effect of wet, warm conditions in the late winter, which slow the spring migration by degrading the snowpack caribou need to travel across. Cow caribou who experienced wet conditions or repeated freeze-thaw events during spring migration were more likely to have their calves outside of the core calving grounds, which is linked to lower calf survival. However, we found little evidence that the timing of spring migration and calving was shifting to earlier dates to accommodate the warmer spring conditions brought to the Arctic by climate change. This phenological mismatch could have population-level effects if caribou are unable to reach the safety of their calving grounds before giving birth.

This project also supported the completion of an in-depth analysis of caribou foraging behavior using GPS collars fitted with video cameras. Videography is a relatively new tool for behavioral analysis of free-ranging animals and provides a highly detailed view of the time budget employed by caribou. This analysis revealed that caribou spend over 40% of their time foraging and provided a species-level break down of plants and fungi consumed by caribou. Past research has demonstrated that lichen makes up a large part of caribou summer diet; the video analysis showed that in addition to lichen, caribou are consuming mushrooms and shrubs at high rates that were previously under-detected. Additionally, researchers documented caribou ceasing foraging behavior to avoid biting insects, demonstrating a behavioral trade-off that could result in lower body condition and overall health.

To further explore behaviors associated with resource selection, co-PIs Fagan and Gurarie and their co-authors built synthetic models comparing several theories of animal movement relative to resource gradients. They found that models where animals tracked gradients of resource availability across space and/or time were more effective than models where animals tracked resource density alone. By incorporating more complex behavioral traits into the models, such as allowing animals to switch

between resource searching modes (e.g. random searching versus following a resource gradient) and between movement modes as a function of their spatial context, this analysis brings a new level of sophistication to the resource selection discussion. These results will help us better understand how caribou make choices about where to go on the landscape as they attempt to maximize their resource intake while also navigating complex social, ecological, and spatial environments.

Key outcomes or other achievements: Nothing to report

What opportunities for training and professional development has the project provided?

To date, the Fate of the Caribou project has recruited three post-doctoral researchers (at SUNY-ESF, University of Montana, and Northern Arizona University) and four PhD students (two at SUNY-ESF, one at Northern Arizona University, and one at University of Maryland). Co-PI Fagan at the University of Maryland has also supported an undergraduate researcher who is assisting with background research and compilation of data on caribou demography. Additionally, Program & Communications Manager Anna Brose attended a two-day workshop on improving communication with the public, which included sessions on facilitating meetings, public speaking, and writing skills. Brose also participated in several Navigating the New Arctic Broader Impact Network trainings, including sessions on using social media to reach communities of interest (April 2022) and strategies for accelerating collaborations (August 2022).

Have the results been disseminated to communities of interest?

The results of our first analyses are fairly recent, but we have begun efforts to disseminate our findings.

Co-PI Anne Gunn co-authored an article on caribou migratory behavior for the World Wildlife Fund's (WWF) *The Circle* magazine, a publication focused on conservation in the Arctic (attached). The article was included in WWF's monthly newsletter, which is sent to 5,458 subscribers; it received 12 website views, 566 Twitter impressions, and reached 179 accounts on Instagram through WWF's social media channels.

Our project was invited to collaborate on an upcoming exhibit on boreal ecology and people with the Smithsonian Institution. The travelling exhibit, titled "Knowing Nature: Stories of the Boreal Forest", will explore the boreal forest as a carbon sink, an area threatened by climate change, and a homeland for many Indigenous Peoples and wildlife species. The Fate of the Caribou project is contributing data and graphics of barren-ground and woodland caribou movements and space use to the exhibit, which is expected to be completed in 2023.

Co-PI Logan Berner at Northern Arizona University completed a series of interviews in December 2021 to introduce our project to audiences in the Phoenix, Arizona region. He appeared in several local and regional news and radio shows to share how our research could help "save Santa's reindeer" and bring awareness to the challenges faced by caribou from climate change to human development. In total, the news segments reached over five million people. While urban and suburban viewers in Arizona are not usually directly impacted by caribou stewardship in the Arctic, it is critical to increase understanding of the impacts of climate change on caribou and northern communities across a broad audience.

Berner's outreach efforts also led to the publication of an article in *The Wildlife Society Bulletin* titled "Interdisciplinary effort to understand caribou challenges" by Dana Kobilinsky. This article highlighted the collaborative nature of our research and reached at least 10,000 wildlife researchers via the Wildlife Society's electronic newsletter. Our work on caribou foraging ecology using GPS camera collars produced

several public articles, including pieces in Canadian Geographic, Arctic Today, and the Geophysical Institute's Alaska Science Forum. Similarly, our project was highlighted in the June issue of the Navigating the New Arctic Community Office newsletter, which is sent to approximately 585 arctic researchers funded through the NSF-NNA initiative.

Co-PI Hebblewhite and Post-Doctoral Researcher Ehlers gave several invited talks on their work with caribou GPS collars fitted with video cameras, including at the NASA Arctic-Boreal Vulnerability Experiment (ABOVE) Yukon Science Seminar Series, ArcticHub Research Group seminar series (November 2021), Tr'ondëk Hwëch'in Government Fortymile Caribou Herd Research Update (February 2022), and a Wildlife Biology Graduate Seminar at the University of Montana (May 2022). These presentations outlined the insights on caribou foraging ecology and reached not only fellow scientists who may be able to use this groundbreaking method in similar studies, but also Fortymile Caribou Herd stewards and decision makers.

Project team members are involved in several professional outreach and collaboration efforts. PI Gurarie is a core member of the Arctic Regional Team of the Global Initiative on Ungulate Migration (GIUM) and participated in a strategy meeting on current caribou research as part of the GIUM Advisory Group meeting in May 2022. Program manager Brose is on the organizing committee for the 2023 joint meeting of the North American Caribou Workshop and Arctic Ungulate Conference (NACW-AUC), which will bring together 300-500 northern ungulate researchers and rights holders to discuss recent research and challenges to Arctic ungulate populations. Her design also won a contest for the 2023 NACW-AUC logo and is featured across conference materials.

Team members Gurarie, Couriot, and Perra traveled to Montréal, Quebec, Canada in August 2022 to participate in the joint meeting of the Ecological Society of America and Canadian Society for Ecology and Evolution. Couriot presented a poster at the conference titled "Complementary methods for identifying calving grounds of barren-ground caribou" (attached). Co-PI Hebblewhite and Postdoctoral Researcher Ehlers participated in the virtual 2021 North American Caribou Workshop to network with other caribou researchers and managers. Hebblewhite and Ehlers also presented research updates at several Fortymile Caribou Herd Working Group meetings (Fall 2021, Spring 2022). These professional outreach efforts have strengthened our collaboration networks and opened new opportunities for data sharing and research cooperation.

Our website, FateOfTheCaribou.esf.edu, features a "Resources" page where project results and other relevant links are available. We recently started a Twitter account (@FateOfCaribou), which will be used to share project results. As detailed above, we are in the process of creating a collaborative storymap and brochure on the shifts in migration of Bathurst caribou, which will be directly shared with communities in the Bathurst Herd's range. As our first few papers are peer-reviewed, we plan to expand our efforts in directly communicating results with our partnering communities.

What do you plan to do during the next reporting period to accomplish the goals?

Building on research questions posed by our partners, and leveraging our development of new behavioral indicators, we are preparing to start several new analyses and projects during the next reporting period. PI Gurarie and Postdoctoral Researcher Couriot will be leading an effort to use behavioral analysis to detect the timing and duration of the rut, or caribou mating period, which has impacts on the timing of calving. They will explore a) whether Indigenous and local knowledges indicate a pattern or environmental trigger for the rut, b) whether the rut can be detected using behavioral cues, and c) how

environmental variables impact rut timing and duration, focusing first on the neighboring Bathurst, Bluenose East, and Beverly-Ahiak caribou herds in north-central Canada. They will also focus on those herds in an ongoing analysis of how those herds' winter ranges are shifting and overlapping, which has critical management implications for First Nations, Métis, and Inuit harvesters. After identifying behavioral cues for the rut, Gurarie and Couriot plan to extend their analysis to compare behavioral differences between male and female caribou during critical periods of the year such as the rut, calving, and winter survival.

Several Postdoctoral Researchers and PhD students will be onboarded to the project during the next reporting period and will begin work on many of our core research questions. PhD student Megan Perra will build on her master's research on the auditory sensitivity of caribou, exploring the acoustic ecology of barren-ground caribou, especially in relation to human development and infrastructure, which is a key concern for our Indigenous partners. PhD student Chloe Beaupré will contribute to the development of behavioral analysis methods to detect rut timing and biting insect harassment, which both have potential impacts on caribou reproductive success and long-term population trends. A Postdoctoral Researcher and PhD student Skye Salganek at NAU will contribute to mapping vegetation changes across the study area and across large spatial and temporal scales, to assess how climate change and herbivory are affecting vegetation communities in caribou range. PhD student Marron McConnell and PI Fagan will continue development of caribou demographic model(s) in consultation with species experts and McConnell will expand her training in the principles of population biology and spatial ecology. A Postdoctoral Researcher at the University of Montana will be recruited to explore the relationship between caribou, snow and ice pack, and wildfire.

We expect to publish several papers from these new initiatives and ongoing analyses in the coming year. Papers in progress include "Seasonal, behavioral, and inter-annual variation in habitat preference of a highly mobile Arctic herbivore" by PIs Gurarie, Fagan, and Hebblewhite and their coauthors, which will be submitted to *Ecology*. Couriot and Gurarie and coauthors are preparing to submit "Complementary definitions and methods for identifying calving grounds of barren-ground caribou" to elucidate the controversial definition of caribou calving grounds. Ongoing analysis by Gurarie will produce a paper on the spatial characteristics of mortality events in the Western Arctic Caribou Herd, which is experiencing disruptions to migration caused by human infrastructure. Gurarie and Couriot also expect to publish a paper on the winter range overlap between the Bathurst, Bluenose East, and Beverly-Ahiak Caribou Herds in north-central Canada. Co-PIs Berner and Goetz anticipate the completion of analysis and a publication on changes in vegetation communities in the range of the Fortymile Caribou Herd in Interior Alaska and western Yukon.

As we complete analyses and our work is peer-reviewed, we plan to greatly increase our outreach efforts and broader impacts. A primary objective for the upcoming reporting period is to engage more directly with caribou co-management boards, including attending the Bathurst Caribou Advisory Committee meeting in December 2022. We anticipate completion of the Bathurst caribou storymap and brochure in partnership with the Wek'èezhii Renewable Resources Board, Tłıchq Government, Government of the Northwest Territories, which will be distributed to communities within the Bathurst herd's range. We also plan to contribute articles and interviews to local news outlets and caribou-focused publications like the *Caribou Trails* newsletter, produced by Alaska Department of Fish and Game, and the Tłıchq Government Lands Protection Department newsletter.

The Fate of the Caribou project is also involved in organizing the 2023 joint meeting of the North American Caribou Workshop and Arctic Ungulate Conference (NACW-AUC), taking place May 8-12, 2023,

in Anchorage, Alaska. We will be leading a two-day workshop for about 50 caribou and ungulate researchers titled “Analysis of caribou movements and geospatial covariates with the TuktTools R package and Google Earth Engine”, wherein we will share the behavioral and other analysis tools we have been developing. Program staff is also involved in the conference planning process, which emphasizes participation from Indigenous and rural rights holders. Dr. Gurarie will also be developing a presentation for the 2023 American Society of Mammologists conference titled “The Determinants of Movement for Large Social Ungulates” which will focus on incorporating social and behavioral cues in addition to environmental covariates when modeling large mammal movements. He has also been invited to speak at the Isaac Newton Institute program “Mathematics of movement: an interdisciplinary approach to mutual challenges in animal ecology and cell biology” Collective Behavior workshop, taking place August 7-11, 2023 in Cambridge, England. We also anticipate sharing our findings at several professional conferences throughout the next reporting period.

PRODUCTS

Books: None

Book Chapters: None

Inventions: None

Journals or Juried Conference Papers:

Berner, L.T., J.J. Assmann, S. Normand, and S.J. Goetz (In Review). IsatTS - an R package for deriving vegetation greenness time series using Landsat satellite data. *Ecography*. (NSF support acknowledged)

Couriot, O.H., M.D. Cameron, K. Joly, J. Adamczewski, M.W. Campbell, T. Davison, A. Gunn, A.P. Kelly, M. Leblond, J. Williams, W.F. Fagan, A. Brose, and E. Gurarie (In Review). Continental synchrony and local responses: climatic effects on spatiotemporal patterns of calving in a social ungulate. *Ecosphere*. (NSF support acknowledged)

Ehlers, L., G. Coulombe, J. Herriges, T. Bentzen, M. Sutor, K. Joly, and M. Hebblewhite. 2021. Critical summer foraging tradeoffs in a subarctic ungulate. *Ecology and Evolution* 11:17835–17872. (NSF support acknowledged)

Fagan, W.F., C. Saborio, T. Hoffman, E. Gurarie, R.S. Cantrell, and C. Cosner (In Press). What’s in a resource gradient? Comparing alternative cues for foraging in dynamic environments via movement, perception, and memory. *Theoretical Ecology*. (NSF support acknowledged)

Gurarie, E., S. Potluri, G. C. Cosner, R. S. Cantrell, and W. F. Fagan. 2021. Memories of migrations past: sociality and cognition in dynamic, seasonal environments. *Frontiers in Ecology and Evolution* 9.

Orndahl, K., L. W. Ehlers, J. Herriges, R. Pernick, M. Hebblewhite, and S. Goetz. 2022. Mapping tundra ecosystem plant functional type cover, height and above-ground biomass in Alaska and northwest Canada using unmanned aerial vehicles. *Arctic Science* 00:1-16. doi.org/10.1139/AS-2021-0044. (NSF support acknowledged)

Licenses: None

Other Conference Presentations / Papers:

Couriot, O., Gurarie, E., Cosby, O., Campbell, M., and Leblond, M. 2022. Complementary definitions and methods for identifying calving grounds of barren-ground caribou. Poster. 2022 Joint Meeting of the Ecological Society of America and Canadian Society for Ecology and Evolution. Montréal, Québec, Canada. August 14-19, 2022.

Ehlers, L. 2022. Behavioral, foraging, and population dynamics of a subarctic ungulate. Wildlife Biology Graduate Seminar. University of Montana, College of Forestry and Conservation, Missoula, MT.

Ehlers, L. 2021. The CariView Experience: Using GPS video-camera collars to better understand foraging ecology and summer diets of barren-ground caribou. Invited talk. NASA ABoVE Yukon Science Seminar Series. Virtual.

Ehlers, L. 2021. Using GPS camera collars to better understand caribou foraging ecology. Invited talk. ArcticHub Research Group Seminar.

Ehlers, L. 2022. The CariView Experience: Using GPS video-camera collars to better understand foraging ecology and summer diets of barren-ground caribou. Invited talk. Tr'ondëk Hwëch'in Government Fortymile Caribou Herd Research Update.

Gurarie, E. 2022. Update on the Fate of the Caribou Project (virtual). Invited talk. Strategy and Updates meeting of the Arctic Regional Team. Global Initiative on Ungulate Migration Advisory Group Meeting. May 23-25, 2022. Marseille, France.

Other Products: None

Other Publications:

Gunn, A., and D. E. Russell. 2022. Caribou culture at risk: Are migrating caribou losing the collective memory they rely on to survive? *The Circle* 1.2022:24–29.

Gunn, A., and D. E. Russell. 2022. Update on the global status of wild reindeer and caribou. *IUCN Deer Specialist Group News* 33:14–29.

Patent Applications: None

Technologies or Techniques:

Gurarie, E., Couriot, O., and Brandão Biebuhr, B. TuktutTools: a package of tools for studying tuktut (caribou) spatial patterns. Publicly available at <https://github.com/ocouriot/TuktutTools>

The Tuktut Tools R package is a set of tools developed by the Fate of the Caribou team that allows researchers to analyze caribou spatial and behavioral patterns. To date, the package includes functions to estimate individual calving times using movement rate analysis, identify migration timing, compute sociality indices (how often individuals are interacting with each other), estimate calving and early rearing areas, delineate overall seasonal and daily ranges, and partition behavior into transient and residential stages using GPS collar data. The package also includes tools to map and animate location data to visualize animal movements more easily. Additional tools are being added to the package as it is developed.

Berner, L.T., Assmann, J.J., Normand, S., and Goetz, S.J. IsatTS - an R package for deriving vegetation greenness time series using Landsat satellite data. Publicly available at <https://github.com/logan-berner/IsatTS>

This package enables users to extract nearly four decades of Landsat satellite surface reflectance measurements for sample locations anywhere on Earth and then generate high-quality time series of vegetation greenness for ecosystem monitoring.

Thesis / Dissertations:

Ehlers, L.P.W. 2022. Spatial behavior, foraging, and population dynamics of a subarctic ungulate. Doctoral dissertation, University of Montana, Missoula, Montana. (NSF funding acknowledged)

Websites or Other Internet Sites: FateOfTheCaribou.esf.edu, twitter.com/FateOfCaribou

PARTICIPANTS

What individuals have worked on the project?

Name	Most senior project role	Nearest person month worked	Describe contribution
Eliezer Gurarie	PI	3	Led the Fate of the Caribou team, organized PI meetings, recruited one Post-Doctoral Researcher, two PhD students, and Program & Communications Manager. Co-authored three published or in-press papers and one poster presentation with more papers in progress. Developed analytical tools presented in the TuktTools R package. Completed several analyses of caribou sociality and habitat use and led collaboration with Indigenous and local partners in the Arctic.
William Fagan	Co-PI	1	Lead development of a synthetic caribou population model. Recruited a PhD student to build the model. Completed analysis and published a paper on measuring foraging behavior using GPS collar movement cues.
Anne Gunn	Co-PI	3	Provided subject matter expertise during development of project research questions and outreach materials. Conducted outreach on the status of and threats to caribou in a popular magazine and among an international deer-species working group. Made introductions and connections between project PIs and Indigenous and governmental partners.

Scott Goetz	Co-PI	1	Participated in project planning meetings, guided remote sensing work
Logan Berner	Co-PI	3	Developed methods to map tundra vegetation using remote sensing, completed analysis to improve understanding of caribou and vegetation dynamics in the Fortymile herd, educated people in Arizona about Arctic environmental change via TV and radio interviews.
Mark Hebblewhite	Co-PI	1	Co-authored two papers, recruited a short-term Post-Doctoral Researcher, participated in project planning meetings, and gave several outreach presentations.
Libby Ehlers	Post doc	4	6-month Post-Doctoral Researcher focused on spatial foraging ecology of the Fortymile caribou population in Alaska and the Yukon Territory. Co-authored two papers and a PhD dissertation and gave several presentations about her research.
Ophélie Couriot	Post doc	9	Authored one in-press paper and one poster presentation with more papers in progress. Developed analytical tools presented in the TuktTools R package. Completed several analyses of caribou sociality and habitat use and led collaboration with Indigenous and local partners in the Arctic.
Marron McConnell	PhD Student	3	Began work on a synthetic model of caribou demography, including gathering information on caribou demography, sociality, and behavior
Megan Perra	PhD Student	1	Began research on the auditory ecology of caribou and impacts of human infrastructure
Chloe Beaupré	PhD Student	1	Began research on sociality and migration memory of caribou, effects of climate change on migration and demographics
Anna Brose	Other Professional	5	Communications and program management. Set up and maintained the project website and Twitter accounts, lead efforts to generate and design outreach materials (storymap, brochure, etc.), administrative support, proofreading publications, and writing project outreach and reporting materials.

Has there been a change in the active other support of the PI/PD(s) since the last reporting period?

Yes No

If Principal Investigators (PIs)/Project Directors (PDs) and co-PIs/co-PDs select “Yes,” they are required to upload their most up-to-date Current and Pending Support document in an NSF-approved format to notify NSF that active other support has changed since the award was made or since the most recent annual report. To access the NSF-Approved formats, you can find them here: <https://www.nsf.gov/bfa/dias/policy/cps.jsp>

What other organizations have been involved as partners?

Global Initiative on Ungulate Migration
Research group
Laramie, WY
Consultation and production of maps for the Bathurst Caribou storymap project

Wek'èezhì Renewable Resources Board
Governmental
Yellowknife, NWT, Canada
Consultation on Bathurst Caribou storymap project and in identifying research priorities

National Park Service
Governmental
Denver, Colorado
Data sharing and research co-authorship

Have other collaborators or contacts been involved?

Yes

No

Tłıchǫ Government, Government of the Northwest Territories Environment and Resources, 2023 North American Caribou Workshop & Arctic Ungulate Conference, Wyoming Migration Initiative, Government of Yukon

IMPACTS

What is the impact on the development of the principal discipline(s) of the project?

During the first year of our project, we developed new analysis tools to explore the relationships between environmental variables and caribou behavior, sociality, and demography. These efforts resulted in a new method for empirically delineating caribou calving grounds from behavioral cues in GPS collar data. Calving grounds are of critical management importance but their boundaries are often disputed; our methods provide a clear definition of greater and central calving grounds and complimentary methods for mapping annual shifts in calving grounds. These new mapping tools will assist researchers and caribou stewards to make critical conservation decisions to protect calving and early rearing areas. These and other behavioral tools are available to other researchers in our TuktuTools R package, making spatial analysis and visualization of caribou movements more accessible.

Our remote sensing team produced a new R package, IsatTS, which allows users to easily download and analyze timeseries of LANDSAT data. This tool will allow researchers across many disciplines to compile vegetation change data across the Arctic more accurately and efficiently.

While synchrony in calving timing has been well documented within barren ground caribou herds, our research demonstrated calving synchrony not only across neighboring herds, but across the North American continent. Further, we demonstrated that local weather conditions affect calving timing in neighboring herds more so than continental climatic patterns. This has important implications on caribou stewardship as climate change makes weather patterns more volatile. Understanding the mechanisms behind calving synchrony within and between herds may allow decision makers to prioritize conservation efforts across multiple herds.

Our team also began work to synthetically model caribou demography, allowing us to explore how various population factors such as adult or calf survival, rut timing, or cow-calf ratios may influence the future of caribou populations, based on historic data. Synthetic models are a powerful analytical and predictive tool to compliment more traditional, fieldwork-heavy methods. Because the lifecycle and social behavior of caribou is complex and highly variable, our development of a flexible synthetic model grounded in decades of data and ecological knowledge will provide a groundbreaking tool for caribou stewards to understand how various demographic and environmental factors may influence populations.

What is the impact on other disciplines?

None to report

What is the impact on the development of human resources?

We have successfully recruited three outstanding Post-Doctoral Researchers, Ophélie Couriot, Libby Ehlers, and Katie Orndahl, and four highly qualified PhD students: Marron McConnell, Megan Perra, Skye Salganek, and Chloe Beaupré. All seven women are experts in their field of study and will apply and expand their skills to some of the primary research questions of our project. Couriot has already contributed significantly to the project through her analysis of caribou demography and behavior, and development of the TuktTools R Package. Ehlers participated as a short-term (six month) appointment and completed research on the foraging ecology of the Fortymile Caribou Herd using GPS collars fitted with cameras to quantify forage preferences at the species level. Orndahl is a remote sensing specialist and will be developing maps and models of vegetation shifts across the range of barren-ground caribou. McConnell comes from a mathematical modeling background and has been instrumental in developing the synthetic model of caribou populations as she pursues her PhD. Perra will be building on her master's thesis work, recently completed at the University of Alaska Fairbanks, exploring the auditory ecology of caribou and human infrastructure. Salganek will use remote sensing to map changes in vegetation communities and caribou responses. Beaupré will be applying and developing our behavioral tools to investigate rut (breeding) timing and social responses to environmental variables and insect harassment.

We plan to recruit another Post-Doctoral Researcher and PhD student before the end of 2022.

What is the impact on teaching and educational experiences?

In addition to the regular faculty teaching responsibilities of several of the project's Primary Investigators, several of our Post-Doctoral Researchers and PhD students have had the opportunity to teach lectures or participate as teaching assistants in their fields of study.

What is the impact on physical resources that form infrastructure?

None to report

What is the impact on institutional resources that form infrastructure?

None to report

What is the impact on information resources that form infrastructure?

We have published several papers and articles detailing the methods and results of our research to date, which will inform future research and caribou management decisions. Development of the storymap narrative of the Bathurst Caribou Herd will also become a useful tool for caribou stewards to illustrate the plight of the herd and its impacts on local communities. We are working with local partners, including the Wek'èezhì Renewable Resources Board, to create a storymap that not only summarizes our research and the local and Indigenous Knowledge about Bathurst caribou, but which can be used in meetings and outreach efforts to demonstrate the shifts in Bathurst caribou population size, range and migration patterns, and the resulting challenges faced by communities who rely on caribou for subsistence and cultural enrichment.

What is the impact on technology transfer?

By formalizing some of our analytical methods into two R packages, we are making these methods readily available to other researchers. R is an open-source coding language that allows for free access to software packages, encouraging collaboration and innovation. Our TuktuTools and IsatST packages are now publicly available and free to use.

What is the impact on society beyond science and technology?

Our ongoing partnerships and outreach efforts with caribou co-management boards and state and territorial governments have directed our research questions to ensure we are producing actionable results that are relevant to the local communities that rely on caribou.

Perhaps most importantly, our research is already being employed to set caribou harvest quotas and guide land management decisions. For example, Co-PI Hebblewhite and Post-Doctoral Researcher Ehlers's work on the foraging ecology of the Fortymile Caribou Herd produced a surface probability habitat map that is being used by the Bureau of Land Management (BLM) in their re-evaluation of Areas of Critical Environmental Concern for caribou calving and summer foraging, and by the Government of the Yukon's environmental assessment for two proposed mine sites. Our continued work on the winter spatial ecology of the Bathurst, Bluenose East, and Beverly Ahiak caribou herds is informing harvest quotas set by the Tłı̨chǫ Government and GNWT. Further, PI Gurarie's work on the resource selection of the Porcupine Caribou Herd in Canada is being used in the Wildlife Conservation and Management Plan for the Yukon North Slope to demonstrate the importance of the proposed Alluaviat/Auguniarvik Indigenous Protected and Conserved Area. In Inuvialuktun, "Alluaviat" means "where the animals and the people travel" and "Auguniarvik" is "where the people go to hunt and harvest". By overlaying Gurarie's habitat maps with the sites and routes used traditionally by Inuvialuit, the Wildlife Management Plan illustrates how critical Alluaviat/Auguniarvik is to the caribou and people of the Yukon North Slope.

Caribou are critical to the culture, lifeways, food security, and well-being of Indigenous and non-Indigenous peoples of the Arctic. Our research is already helping local communities and caribou

management boards make more informed decisions about the harvest and stewardship of caribou and their habitat. As we move forward, our primary goal is to continue producing actionable results that help inform on-the-ground caribou management.

What percentage of the award's budget was spent in a foreign country?

0.34% of budget spent in Canada for ESA conference

CHANGES / PROBLEMS

Changes in approach and reason for change: Nothing to report

Actual or Anticipated problems or delays and actions or plans to resolve them: Nothing to report

Changes that have a significant impact on expenditures: Nothing to report

Significant changes in use or care of human subjects: Nothing to report

Significant changes in use or care of vertebrate subjects: Nothing to report

Significant changes in use or care of biohazards: Nothing to report

Has there been a change in your primary performance site location from the originally proposed? If so, please provide the location of your new primary performance site and reason for the change in location.

Nothing to report